

Sanicro® 35 – Bridging the gap between stainless and Ni-based alloys

Outokumpu Ultra range datasheet

General characteristics and properties

The Ultra range consists of stainless steel and nickel based alloys meant for extremely corrosive environments (PRE > 27).

Sanicro® 35 is a newly developed alloy combining the best features of a high performance austenitic stainless steel and nickel based alloys. This grade is our latest addition to the Ultra range, it has excellent corrosion resistance in combination with a high mechanical strength.

Sanicro® 35 in a nutshell:

- Excellent resistance to pitting and crevice corrosion
- Excellent resistance to stress corrosion cracking (SCC)
- High resistance to uniform corrosion in acid and caustic environments
- High resistance to erosion-corrosion
- Very high mechanical strength
- Good weldability using nickel based alloy consumables
- Good fabricability, i.e. machining and forming

Chemical composition

Table 1

| Alloy designations | | | | Performance | | | | Typical chemical composition, % by mass | | | | | | |
|---------------------------|--------|------|--------|-------------|----------------------|--------------------------|-----------------|-----------------------------------------|-------|------|------|------|--------|--|
| Outokumpu name | EN | ASTM | | PRE | A ¹⁾ % | R _{p0.2} MPa | Grade family | C | Cr | Ni | Mo | N | Others | |
| | | Type | UNS | | | | | | | | | | | |
| Sanicro® 35 ²⁾ | – | – | N08935 | 52 | 40 | 425 | A | 0.02 | 27.0 | 35.5 | 6.4 | 0.27 | Cu | |
| For comparison | | | | | | | | | | | | | | |
| Ultra 904L | 1.4539 | 904L | N08904 | 34 | 35 | 240 | A | 0.01 | 19.8 | 24.2 | 4.3 | – | 1.4Cu | |
| Ultra 254 SMO | 1.4547 | – | S31254 | 43 | 35 | 320 | A | 0.01 | 20.0 | 18.0 | 6.1 | 0.20 | Cu | |
| Forta SDX 2507 | 1.4410 | – | S32750 | 43 | 20 | 550 | D | 0.02 | 25.0 | 7.0 | 4.0 | 0.27 | – | |
| Alloy 625 ³⁾ | – | – | N06625 | 51 | 30 ⁴⁾ | 414 ⁴⁾ | A | 0.01 | 20–23 | >58 | 8–10 | – | Nb+Ta | |

Grade family: A = austenitic, D = duplex. ¹⁾ Elongation reference varies between different standards, for coil the standard typically uses A₈₀ – otherwise see footnote for specific grade. ²⁾ Min. values hot-rolled and cold-rolled ≤ 6.35 mm acc. to ASTM B625. ³⁾ Not produced by Outokumpu. ⁴⁾ Values acc. to ASTM B443.

Sanicro® 35 is a trademark owned by Alleima AB and produced as plate and sheet by Outokumpu under a license agreement.

PRE = %Cr + 3.3 x %Mo + 16 x %N

Values for R_{p0.2} yield strength and the A₈₀ for elongation are according to EN 10088-2 min. values for cold rolled strip. Chemical compositions and PRE calculations are based on Outokumpu typical values.

Please see values for other product forms at steelfinder.outokumpu.com

Applications

Due to its extremely good pitting and crevice corrosion properties, Sanicro® 35 is particularly suitable for applications where seawater is used for cooling or heating. Sanicro® 35 also has a high resistance to uniform corrosion in acid environments, making it suitable for a variety of applications. It is an attractive material of choice for applications within the oil and gas industry where H₂S may be present, due to its high resistance to stress corrosion cracking.

Corrosion resistance

Uniform corrosion

Due to the combination of high contents of nickel, chromium and molybdenum, Sanicro® 35 has good resistance to many commonly found acids, such as sulfuric acid, nitric acid, phosphoric acid and organic acids.

Sanicro® 35 has better resistance in hydrochloric acid compared to stainless steels with a lower chromium and molybdenum content and can be useful in environments where moderate levels of hydrochloric acid is present. See Figure 1.

In low to intermediate concentrations of sulfuric acid, the resistance of Sanicro® 35 is better than Ultra 904L, see Figure 2. In chloride contaminated sulfuric acid, Sanicro® 35 can be expected to offer significantly better resistance than Ultra 904L and Ultra 254 SMO, see Table 2.

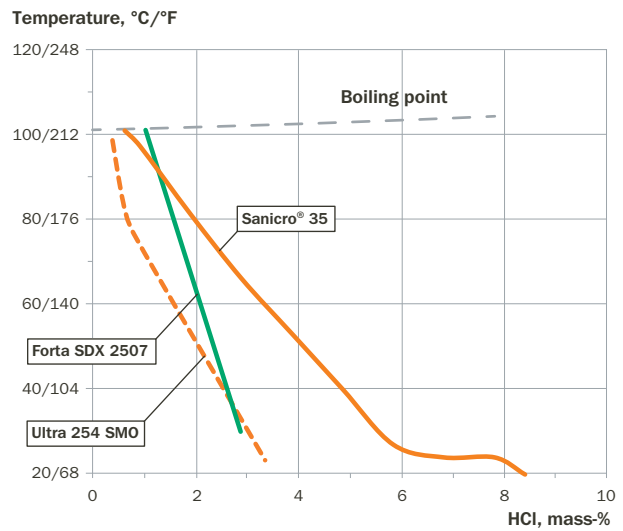


Fig. 1. Isocorrosion diagram for Sanicro® 35 in hydrochloric acid. The line represents a limit, below which the corrosion rate is expected to be lower than 0.1 mm/year. Other grades are included for comparison.

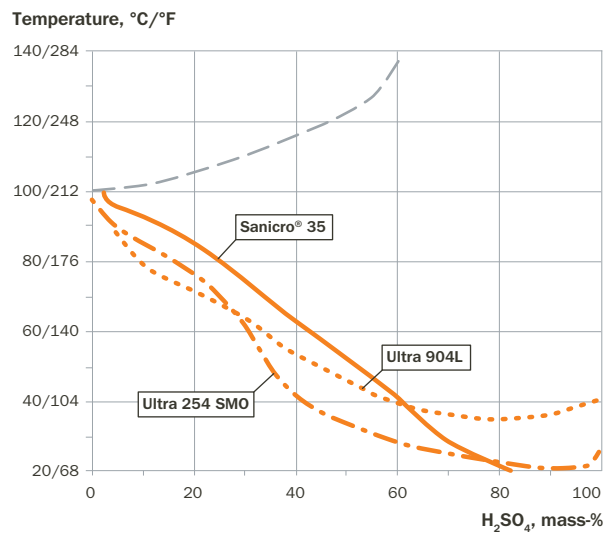


Fig. 2. Isocorrosion diagram for Sanicro® 35 in sulfuric acid. The line represents a limit, below which the corrosion rate is expected to be lower than 0.1 mm/year. Other grades are included for comparison.

Uniform corrosion rates (mm/year) after testing in 20 weight% sulfuric acid according to ISO 18069.

Table 2

| Alloy designation | 0 ppm chlorides | | | 200 ppm chlorides | | 2,000 ppm chlorides |
|-------------------|-----------------|------|-------|-------------------|------|---------------------|
| | 60°C | 80°C | 100°C | 60°C | 80°C | 60°C |
| Sanicro® 35 | – | 0.00 | 1.92 | – | 0.00 | 0.00 |
| Ultra 904L | 0.05 | 1.16 | – | 0.44 | 0.42 | 0.48 |
| Ultra 254 SMO | 0.15 | 1.40 | – | 0.59 | 2.34 | 0.84 |
| Alloy 625 | 0.05 | 0.30 | 0.33 | 0.17 | 0.12 | 0.97 |

PRE, CPT and CCT data, typical values.

Table 3

| Alloy designation | PRE | CPT [°C] | | CCT [°C] |
|-------------------|-----|-------------------------|--------------------------|--------------------------|
| | | ASTM G150 ¹⁾ | ASTM G48 E ²⁾ | ASTM G48 F ²⁾ |
| Sanicro® 35 | 52 | >90 | 85 | 45 |
| Ultra 904L | 34 | 58 ± 3 | 40 | 10 |
| Ultra 254 SMO | 43 | 87 ± 3 | 65 | 35 |
| Alloy 625 | 51 | >90 | 90 | 25 |

¹⁾ Wet ground surfaces, P320 grit.

²⁾ Dry ground surfaces, P120 grit.

Figure 3 shows the effect of chloride addition on the isocorrosion curves in sulfuric acid.

Sanicro® 35 performs well in oxidizing acids, where the high chromium content is beneficial.

Sanicro® 35 also has good resistance to uniform corrosion in alkaline environments, such as sodium and potassium hydroxide solutions. Tests performed at 120 °C showed corrosion rates below 0.1 mm/year in sodium hydroxide concentrations between 40 and 70%.

Pitting and crevice corrosion

Resistance to localized corrosion such as pitting, and crevice corrosion is determined mainly by the chromium, molybdenum and nitrogen content in the material. This is often illustrated using the pitting resistance equivalent (PRE) for the material, which can be calculated using the formula: $PRE = \%Cr + 3.3 \times \%Mo + 16 \times \%N$. Although the PRE typically exhibits good agreement with practical performance, it is only a theoretical approximation. A more reliable means to rank the alloys, based on laboratory testing, is by critical pitting temperatures (CPT) and critical crevice corrosion temperatures (CCT) of the material.

PRE, CPT and CCT data according to commonly used methods are listed in Table 3. The CPT value for Sanicro® 35 indicates a pitting resistance significantly higher than Ultra 254 SMO, and on a similar level as Alloy 625. Sanicro® 35 is resistant up to the maximum tested temperatures of 90°C in ASTM G150 and has a CPT of 85°C in ASTM G48 method E.

Table 4 shows the results from 90-day corrosion tests in natural and chlorinated seawater at various temperatures. The results show that Sanicro® 35 has excellent resistance to both pitting and crevice corrosion in seawater, even at elevated temperatures and chlorinated conditions.

90-day corrosion tests in natural and chlorinated seawater at various temperatures.

Table 4

| Test condition | Sanicro® 35 | | Alloy 625 | |
|------------------------------------|-------------|---------|-----------|---------|
| | Pitting | Crevice | Pitting | Crevice |
| 30 °C Natural | No | No | No | Yes |
| 45 °C Chlorinated 0.5 ppm Cl | No | No | No | No |
| 80 °C Chlorinated 0.5 ppm Cl | No | – | No | – |

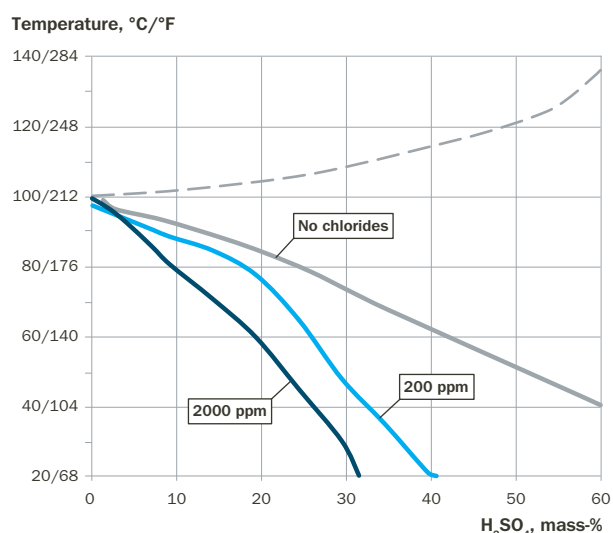


Fig. 3. Performance comparison of Sanicro® 35 in sulfuric acid with and without chloride addition.

Stress corrosion cracking

Due to its high nickel content, Sanicro® 35 exhibits excellent resistance to chloride induced stress corrosion cracking (SCC). Resistance to cracking can be expected in many environments where type 316L and similar grades would be susceptible to SCC. Cracking may occur in the most extreme conditions, such as in the boiling 45% MgCl₂ U-bend test. Even then, Sanicro® 35 exhibits higher resistance than 6Mo grades such as Ultra 254 SMO. See Table 5.

The grade complies with NACE MR0175/ISO 15156-3 as a type 4a and 4c material, with significantly higher environmental limits than 6Mo grades like Ultra 254 SMO. Additionally, cold worked Sanicro® 35 (965 and 1,240 MPa) has been tested in a NACE MR0175/ISO 15156 Test Level VI environment according to NACE TM0198 with no indication of SCC.

Number of cracked U-bend samples after testing in 45% MgCl₂ at boiling conditions for 24 hours.

Table 5

| Alloy designation | Cracked samples |
|-------------------|-----------------|
| Sanicro® 35 | 1/3 |
| Ultra 254 SMO | 3/3 |

Mechanical Properties

Table 6 shows the mechanical properties at room temperature for flat rolled products, data according to ASTM B625, EN 10088 and ASTM B443 when applicable. Table 7 indicates the mechanical values at elevated temperatures.

Mechanical properties at 20 °C

Table 6

| Alloy designation | Product form | Min. yield strength $R_{p0.2}$ [MPa] | Min. yield strength $R_{p1.0}$ [MPa] | Tensile strength R_m [MPa] | Min. elongation A [%] |
|-----------------------------|------------------------------------|--------------------------------------|--------------------------------------|------------------------------|-------------------------|
| Sanicro® 35 ¹⁾ | Sheet | 425 | – | 750 | 40 |
| | Plate < 6.35 mm | 425 | – | 750 | 40 |
| | Plate ≥ 6.35 mm | 350 | – | 700 | 40 |
| Ultra 254 SMO ²⁾ | Cold rolled | 320 | 350 | 650–850 | 35 |
| | Hot rolled | 300 | 340 | 650–850 | 35 |
| | Plate | 300 | 340 | 650–850 | 40 |
| Alloy 625 ³⁾ | Cold rolled sheet /strip | 414 | – | 827 | 30 |
| | Cold rolled plate ≤ 9.5 mm | 379 | – | 758 | 30 |
| | Hot rolled sheet and plate ≤ 70 mm | 379 | – | 758 | 30 |

Values according to

¹⁾ ASTM B625

²⁾ EN 10088-2

³⁾ ASTM B443 (Grade 1 not produced by Outokumpu)

Mechanical properties at elevated temperatures

Table 7

| Temperature [°C] | Thickness [mm] | $R_{p0.2}$ [MPa] | $R_{p1.0}$ [MPa] |
|------------------|----------------|------------------|------------------|
| 100 | < 6.35 | 350 | 375 |
| | 6.35 ≤ t ≤ 50 | 250 | 280 |
| 200 | < 6.35 | 300 | 325 |
| | 6.35 ≤ t ≤ 50 | 215 | 250 |
| 300 | < 6.35 | 275 | 300 |
| | 6.35 ≤ t ≤ 50 | 200 | 240 |
| 400 | < 6.35 | 250 | 275 |
| | 6.35 ≤ t ≤ 50 | 170 | 210 |
| 450 | < 6.35 | 250 | 275 |
| | 6.35 ≤ t ≤ 50 | 160 | 200 |

Physical properties

Table 8

| Temperature °C | Density [kg/dm ³] | Modulus of elasticity [GPa] | Coefficient of thermal expansion 30-T °C [10 ⁻⁶ /K] | Thermal conductivity [W/(m x K)] | Thermal capacity [J/(kg x K)] | Electrical resistivity [Ω x mm ² /m] | Magnetizable |
|----------------|-------------------------------|-----------------------------|----------------------------------------------------------------|----------------------------------|-------------------------------|-------------------------------------------------|--------------|
| 20 | 8.1 | 190 | – | 10.0 | 450 | 1.0 | No |
| 100 | – | 185 | 14.0 | 12.0 | 470 | – | – |
| 200 | – | 180 | 14.5 | 13.5 | 500 | – | – |
| 300 | – | 175 | 15.0 | 15.5 | 510 | – | – |
| 400 | – | 170 | 15.5 | 17.0 | 530 | – | – |

Fabrication

Forming

Sanicro® 35 has a very good formability making it suitable for all sheet and plate forming processes as indicated by the high elongation value. Despite its high strength, Sanicro® 35 retains a very high fracture strain in comparison to other stainless steel and Ni-base alloys. However, the higher yield stress must be considered e.g. in terms of higher forces during forming and increased spring back after forming. Also, a higher demand on the tool material and lubricant should be taken into account. Both of these effects can be reduced, if down gauging is possible due to the increased strength.

The excellent forming properties of Sanicro® 35 can be quantified in several formability metrics. The r-value describes a material's tendency towards thinning in a certain forming direction, with higher values indicating lower tendency towards thinning. With values close to 1 in three tensile directions Sanicro® 35 is not only resilient to thinning but also shows almost isotropic behavior (see Figure 4) and therefore little to no earing.

The limiting factor for most sheet metal forming operations is the formability in plane strain condition. As indicated in Figure 5, Sanicro® 35 shows equal or slightly better formability when compared with Alloy 625 and Ultra 254 SMO. This is also the case for other formability metrics like the limiting dome height (LDH), which measures the ability of a material to withstand stretch forming. Here, Sanicro® 35 outperforms Alloy 625 by more than 10% and behaves similar to Ultra 254 SMO. The same can be said for the hole expansion ratio (HER), which determines the edge stretching ability of sheet metal, an attribute needed e.g. for the crimping of edges. For this metric an even stronger outperformance of more than 30% can be observed for Sanicro® 35 when compared to Alloy 625.

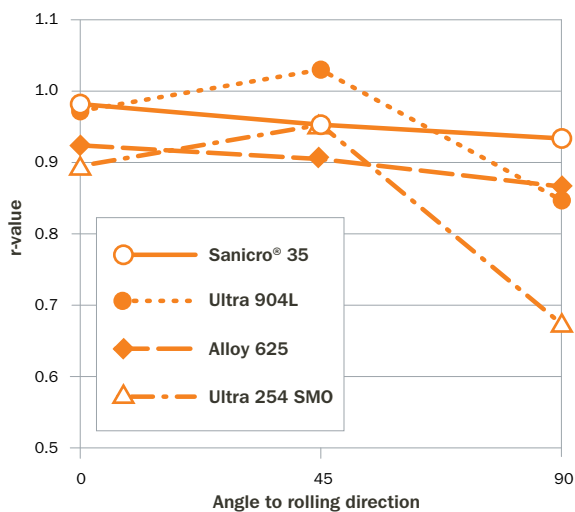


Fig. 4. r-values for some high performance alloys.

Welding

The weldability of Sanicro® 35 is good and welding is suitable using TIG (GTAW), MIG/MAG (GMAW), MMA (SMAW). For multi pass welding it is recommended to use TIG welding for the root pass. Welding should be undertaken with low heat input, maximum 1.2 kJ/mm, and an interpass temperature of maximum 100°C.

Nickel based alloy UNS N06059 (ERNiCrMo-13, NiCr23Mo16) e.g. Avesta P16 is recommended as filler material. Use of filler material is recommended for this material. Autogenous welding should typically be avoided but if necessary, followed by appropriate and qualified post weld heat treatment.

Argon is recommended as shielding gas with TIG welding to achieve the best combination of mechanical properties and corrosion resistance of the welded joints. Pure argon, Ar + 2 % N₂, Pure N₂ or N₂ + 5–10% H₂ can be used as backing gas provided that hydrogen addition is allowed according to given application standard.

For MIG/MAG welding Ar + 20–40% He + 1–3% CO₂ is recommended as shielding gas for optimal corrosion resistance and arc stability. Pure Ar can also be utilized.

Preheating and post-weld heat treatment are not necessary under normal circumstances. To maintain full corrosion resistance of the welded joint, welding must be followed by thorough cleaning to ensure the removal of all oxides and heat tint.

Welding of fully austenitic stainless steels and nickel based alloys often involves the risk of hot cracking in the welded joints if the weldment is under restraint. Due to the low level of impurities in Sanicro® 35, the risk of hot cracking is lower than for most nickel based alloys.

Joint type selection should be made according to recommendation for high alloyed austenitic stainless steels and nickel based alloys.

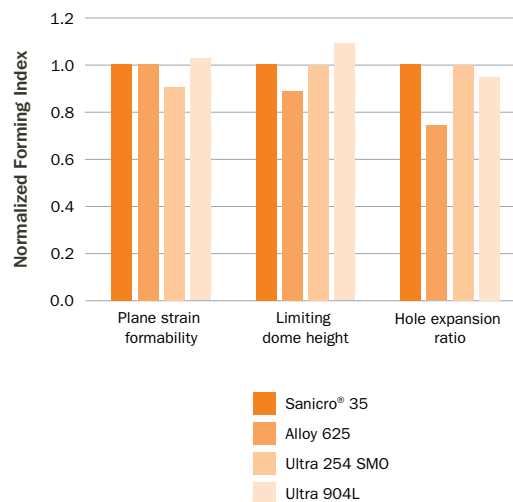


Fig. 5. Formability ranking of some high performance alloys.

Machining

High performance grades such as austenitic stainless steels and nickel-base alloys are generally perceived as challenging to machine due to their high work-hardening rate and toughness as well as their tendency towards built-up edge. This is especially the case for Sanicro® 35 due to its increased proof strength. However, with the right tools and setup Sanicro® 35 can be successfully machined.

The machinability of a certain grade can be described by the tool life, that is a function of the cutting speed. High cutting speeds typically corresponding to lower tool life, tested through varying the cutting speed until a preset tool life is achieved, this enables machinability comparison of different grades. In Figure 6 Sanicro® 35 is compared to Alloy 625 in terms of face milling and indexable drilling. For both processes Sanicro® 35 shows a superior machinability with roughly 20 % higher cutting speeds for 5 (V5) and 10 minutes of tool life (V10) in face milling and more than 50 % higher cutting speed for 20 minutes of tool life (V20) in indexable drilling. This enables either a higher productivity or a reduction in tooling costs when machining Sanicro® 35 as opposed to Alloy 625.

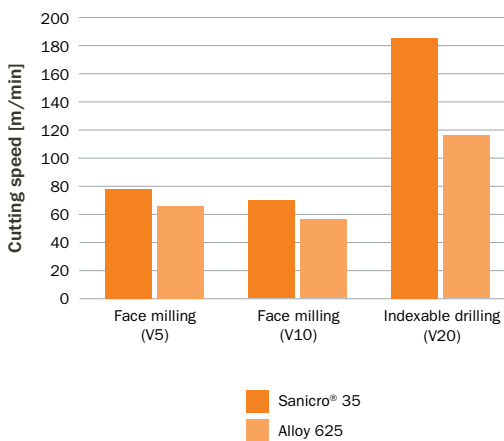


Fig. 6. Machinability index comparing Sanicro® 35 with Ni-base Alloy 625.

Products

Sanicro® 35 is available as cold rolled sheet and plate in thicknesses of 0.4–5.5 mm with a width of up to 1,350 mm.

Sanicro® 35 is available as hot rolled plate in thicknesses of 10–50 mm with a width of up to 2,000 mm.

Standards and Approvals

Sanicro® 35 as sheet and plate is included in ASTM B625 as UNS N08935.

Sheet, plate, bar and seamless tube and pipe are covered by the ASME Code Case 2952-2, Boiler and Pressure Vessel Code, Section VIII, Division I and II.

Compliance with NACE MR0175/ISO 15156-3:2015, (Petroleum, Petrochemical, and Natural Gas Industries - Materials for Use in H S-Containing Environments in Oil and Gas Production - Part 3: Cracking-Resistant CRAs (Corrosion-Resistant Alloys) and Other Alloys) for type 4a and type 4c materials. Compliance with ANSI/NACE MR0103/ISO 17495-1:2016, (Petroleum, petrochemical and natural gas industries-Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments) for highly alloyed austenitic stainless steels and nickel alloys.

A pre-approval for Particular Material Appraisal (PMA), TÜV is available, Pre-PMA no:1326W232560.

Seamless tube and pipe are included in ASTM B163 and ASTM B677. Sanicro® 35 as bar and wire products are included in ASTM B649.

Contacts and enquiries

Contact us

Our experts are ready to help you choose the best stainless steel product for your next project.

www.outokumpu.com/contact

Own notes

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Working towards forever.

We work with our customers and partners to create long lasting solutions for the tools of modern life and the world's most critical problems: clean energy, clean water, and efficient infrastructure. Because we believe in a world that lasts forever.

| outokumpu classic | | | outokumpu pro | | | | | |
|----------------------------------------------|---------------------------------------|-----------------------------------------------|----------------------------------------------|--------------------------------------------------|------------------------------|--------------------------------------------|-----------------------------------------|---------------------------------|
| Moda Mildly corrosive environments | Core Corrosive environments | Supra Highly corrosive environments | Forta Duplex & other high strength | Ultra Extremely corrosive environments | Dura High hardness | Therma High service temperatures | Prodec Improved machinability | Deco Special surfaces |

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